OH (1720 MHz) Maser Search Toward the Large Magellanic Cloud

C. L. Brogan[1,2], W. M. Goss[1], J. Lazendic[3], A. J. Green[4]

cbrogan@ifa.hawaii.edu

ABSTRACT

We have carried out a sensitive search for OH (1720 MHz) masers in the Large Magellanic Cloud (LMC) toward five regions using the Australia Telescope Compact Array (ATCA). Our source list includes the 30 Doradus region, and four supernova remnants (SNRs): N44, N49, N120, and N132D. These data have a typical resolution of $\sim 8''$ and rms noise levels of 5-10 mJy beam^{-1}. We have detected OH (1720 MHz) masers in the NE part of 30 Doradus and toward the SNR N49. The OH (1720 MHz) maser emission in 30 Doradus is coincident with a cluster of young stars known as "Knot 1", and is almost certainly of the star formation variety. Our spectral resolution (0.68 km s^{-1}) is insufficient to detect the Zeeman effect from the strongest ($\sim$ 320 mJy beam^{-1}) of the 30 Doradus OH (1720 MHz) masers, leading to an upper limit to the field strength of 6 mG. The weak OH (1720 MHz) maser emission (35 mJy beam^{-1}) detected toward the LMC SNR N49 is located just west of a previously identified CO cloud, and are indicative of an interaction between the SNR and the molecular cloud. Although the statistics are low, the detection rate seems consistent with that seen for Galactic star forming region and SNR type OH (1720 MHz) masers – both of which are low.

Subject headings: ISM:clouds — ISM:individual (30dor, N49) — Galaxies: Magellanic Clouds — ISM:magnetic fields — masers — polarization

[1]National Radio Astronomy Observatory, P. O. Box O, 1003 Lopezville Road, Socorro, NM 87801, USA; mgoss@aoc.nrao.edu

[2]Current address: Institute for Astronomy, 640 North A'ohoku Place, Hilo, HI 96720, USA; cbrogan@ifa.hawaii.edu

[3]Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA; lazendic@head.cfa.harvard.edu

[4]Astrophysics Department, School of Physics, University of Sydney, Sydney, NSW 2006, Australia; aGreen@physics.usyd.edu.au

1. INTRODUCTION

In recent years, it has become clear that there are at least two major subclasses of Galactic OH (1720 MHz) masers. One is associated with young massive star forming regions and are almost always accompanied by mainline OH maser emission at 1665 and 1667 MHz (see, however, §4.1). These masers are thought to be radiatively pumped in dense gas with $n \sim 10^7$ cm^{-3}, low kinetic temperatures of ~ 30 K, can be quite strong ~ 100 Jy, and are often variable (see for example Cragg, Sobolev, & Godfrey 2002; Caswell 2004). We will call masers of this subclass SFR (star forming region) OH (1720 MHz) masers. In a recent survey of 200 known mainline maser locations in the southern sky, Caswell (2004) detected 34 SFR OH (1720 MHz) masers (i.e. in 17% of the sample). Caswell also finds that SFR 1720 MHz masers occur preferentially where OH 6035 MHz masers are also found. Szymczak & Gérard (2004) report the results of a blind survey for 1612, 1665, 1667, and 1720 MHz masers at 100 sites of SFRs with known 6668 MHz CH_3OH maser emission. These authors found 55 mainline OH maser sources and only 6 OH (1720 MHz) maser sources (all with accompanying mainline emission) toward the methanol maser sites. Thus SFR OH (1720 MHz) maser emission is rare compared to mainline OH and methanol masers.

The second kind of OH (1720 MHz) maser is associated with supernova remnants (SNRs) that are interacting with nearby molecular clouds. This subclass is not typically accompanied by mainline masers, tend to have significantly lower brightness temperatures than their SFR cousins, and have correspondingly large maser spot sizes (see for example Frail et al. 1996; Claussen et al. 1999, 2002; Hoffman et al. 2003). However, a recent OH study of the SNR G349.7+0.3 by Lazendic et al., in prep. has detected a weak OH (1665 MHz) maser in the vicinity of the OH (1720 MHz) masers. Because this remnant is quite distant (~ 22 kpc) the relationship of the two maser types is uncertain. SNR OH (1720 MHz) masers have been found toward 19 SNRs, or 10% of the known SNRs in our Galaxy (Green et al. 1997; Frail et al. 1996; Koraleskey et al. 1998). In addition, a number of masers have also been detected toward the circumnuclear disk (CND) at the Galactic center which have properties similar to the SNR class (Yusef-Zadeh et al. 1999). Maser theory suggests that isolated SNR OH (1720 MHz) masers can be pumped efficiently by collisions behind C-type (non-dissociating) shocks when an SNR encounters a nearby molecular cloud. The masers can only be efficiently pumped when the post-shock molecular gas has densities of $\sim 10^5$ cm^{-3} and temperatures between 50 K $\lesssim T \lesssim$ 125 K (e.g. Lockett, Gauthier, & Elitzur 1999; Wardle 1999). Indeed, CO molecular line observations of SNR OH (1720 MHz) masing regions (Frail & Mitchell 1998) indicate that the gas properties are in agreement with these theoretical expectations. Hence, observations of this OH maser line can serve as a powerful probe of SNR/molecular cloud interactions.

From these descriptions it is clear that both SFR and SNR type OH (1720) MHz masers are useful probes of the physical conditions present at the locations in which they are found. Another advantage of observing the OH (1720 MHz) maser line is that it provides a way to measure the strength of the magnetic field via Zeeman splitting of the circularly polarized emission from the maser. The recent surveys of Caswell (2004) and Szymczak & Gérard (2004) suggest that Galactic SFR OH (1720 MHz) masers have magnetic field strengths in the range 1-16 mG. Zeeman observations toward SNR OH (1720 MHz) masers in our Galaxy have resulted in magnetic field detections between 0.2 and 4 mG (see Brogan et al. 2000, and references therein).

The Large Magellanic Cloud (LMC) provides a unique opportunity to study the masers of a galaxy other than our own. One of the advantages of studying sources in the LMC is that their distances are known to be near the LMC's distance of ~ 50 kpc since this galaxy is viewed almost face-on (Feast 1991). Moreover, the relatively close distance, ensures that we can observe masers with typical Galactic luminosities, rather than so called megamasers, which seem to require very special physical conditions. For example, some of the strong Galactic SFR type masers would have flux densities of ~ 4 Jy beam^{-1} at the distance of the LMC (Gaume & Mutel 1987), while the strongest Galactic SNR type masers would have peak flux densities of ~ 200 mJy beam^{-1} (Claussen et al. 1997; Yusef-Zadeh et al. 1999).

In this paper we present the results of a limited OH (1720 MHz) maser search toward several LMC SNRs and the 30 Doradus region using the Australia Telescope Compact Array (ATCA). Although we have concentrated on SNRs, a number of LMC H II regions (in close proximity to the target SNRs) are also included in our survey. The detection of OH (1720 MHz) masers in LMC SNRs and SFRs will serve several purposes: (1) it will help to identify such interactions for future molecular investigation; (2) if strong masers are observed we will have the rare chance to detect extragalactic magnetic field strengths directly; and (3) we will gain further insight into the production of masers in a low metallicity environment; previous observations of other masing lines in the LMC have yielded unusually low detection rates (see for example Scalise & Braz 1982; Beasley et al. 1996).

1.1. SNR candidates

Some ~ 40 LMC SNRs are currently cataloged (see Williams et al. 1999). However, given the long observing times needed to detect relatively weak OH (1720 MHz) masers, we chose SNRs with the greatest likelihood of success for our initial survey. Two of our candidates are the LMC SNRs N49 (0525-66.1) and N132D which were shown by Banas et al. (1997) to be spatially and kinematically associated with molecular clouds from

SEST observations of CO(2 − 1). These two remnants also show X-ray and radio limb-brightened morphologies which are thought to arise when an SNR interacts with dense molecular material. Dickel & Milne (1998) have recently used the ATCA to study the radio emission from five mature SNRs in the LMC and two of these: N120 (0519-69.7), and N44:shell 3 (0523-679) are associated with H II region complexes, and show morphologies similar to N49. Therefore, these four remnants represent an ideal starting place to look for SNR OH (1720 MHz) masers in the LMC.

In addition, a brief unpublished OH (1720 MHz) maser search of the 30 Doradus region by D. A. Roberts (2000 private communication) with the ATCA in 1997 has already resulted in the detection of a $\sim$ 380 mJy OH (1720 MHz) maser toward the 30 Dor region. Thus we have included this region in our current survey.

2. OBSERVATIONS

Table 1 gives the observing parameters of our 1720 MHz Australia Telescope Compact Array observations taken between Jan. 27 and Feb. 2, 2001. These data were taken using the 6C 6 km baseline configuration, and a 4 MHz bandwidth. All of the data were reduced and imaged using the MIRIAD software package. Flux and bandpass calibration were carried out using a single long observation of 1934-638 at the beginning of each run, while phase calibration information was derived from more frequent observations of 0407-658. For N44, N49, N120, and N132D we recorded two orthogonal linear polarizations, while for 30 Dor we also recorded the cross-correlations allowing us to image this region in RCP (right circular polarization) and LCP (left circular polarization), as well as Stokes I. As a result the spectral resolution of the 30 Dor data is a factor of two worse than for the other sources. The phase calibrator 0407-658 was also used to determine the polarization leakage terms for the 30 Doradus data.

For the four SNR fields, an average of the inner 75% of the band was used to remove the continuum emission in the *UV* plane. For 30 Doradus the channels containing the maser emission near the center of the band were not used in the continuum subtraction. A continuum subtracted line cube was then created covering the FWHM primary beam ($\sim 30'$), and using natural weighting in order to achieve the maximum possible sensitivity. The resulting single pixel spectral rms noise level for each source is also shown in Table 1. Each cube was then searched for maser emission; our detections are described in §3. At the distance of the LMC (50 kpc) $\sim$ 1 pc=$4''$. All velocities are presented in the LSR reference frame.

In addition to the 1720 MHz data presented here, we also reduced archival ATCA data from May 5, 1997 at 1665 and 1667 MHz in a manner similar to that described above in order to determine whether any mainline masers are present toward the 30 Doradus region, and the SNRs N49 and N44. Approximately 2.6 hours were spent on each of these sources at both 1665 and 1667 MHz. No mainline masers were detected down to an rms noise level of ~ 20 mJy beam^{-1} (also see Brooks & Whiteoak 1997, who obtained an rms noise of ~ 10 mJy beam^{-1}).

3. RESULTS

OH (1720 MHz) masers were detected toward the NE part of 30 Doradus and toward the SNR N49. At the distance of the LMC, thermal emission at 1720 MHz would be undetectable, if not simply resolved out. No maser detections were made toward N44, N120 (including the associated H II regions), or N132D. The spectral line 1σ rms noise levels achieved toward each source are listed in Table 1. Details of the OH maser detections are described below.

3.1. OH (1720 MHz) Masers in 30 Doradus

In total, three distinct OH (1720 MHz) maser spots are detected toward 30 Doradus near $05^{\mathrm{h}}38^{\mathrm{m}}45.0^{\mathrm{s}}$, $-69°05'07.5''$. Figure 1 shows a Stokes I= RCP+LCP image of the strongest 30 Doradus OH (1720 MHz) maser channel at v_{lsr} = 243.0 km s^{-1}. In addition to the strongest spatially unresolved maser (30Dor_OH(1)) in Figure 1, with a peak flux density of I$\sim$ 318 mJy beam^{-1}, there is a second weaker maser spot $\sim 10''$ to the SE (30Dor_OH(2)) with a peak Stokes I flux density of ~ 28 mJy beam^{-1} ($\sim 6\sigma$). Figure 2 shows the RCP and LCP profiles toward the peak 30Dor_OH(1) maser position. The third 30 Doradus OH maser (30Dor_OH(3)) is apparent in Fig. 2 at a velocity of 245.1 km s^{-1} and peak LCP flux density of ~ 25 mJy beam^{-1} ($\sim 6\sigma$). The 30Dor_OH(3) maser is located within $\sim 1.5''$ of 30Dor_OH(1). The 30Dor_OH(1) and 30Dor_OH(2) masers are predominantly right circularly polarized while 30Dor_OH(3) is left circularly polarized (see Fig. 2). No linear polarization was detected down to the rms noise level of 5 mJy beam^{-1}.

These results are in good agreement with the previous epoch of unpublished ATCA 1720 MHz data from 1997 toward 30 Doradus (D. Roberts, 2000 private communication). The 1997 data have a peak Stokes I flux density of 380 mJy beam^{-1}, rms noise ~ 12 mJy beam^{-1}, spatial resolution of $6''$ and a velocity resolution of 0.4 km s^{-1}. The apparent decrease in peak flux density of the current data is consistent with the strongest 30 Dor maser being

spectrally unresolved with 0.82 km s^{-1} velocity resolution. Therefore, the maser does not appear to be significantly variable on a four year timescale.

An attempt was also made to measure the magnetic field strength of the 30 Doradus OH (1720 MHz) maser emission using the Zeeman effect. Figure 2 shows the observed Stokes RCP and LCP emission profiles. At the current velocity separation 0.68 km s^{-1} (0.82 km s^{-1} velocity resolution), no frequency shift is apparent between the RCP and LCP profiles. A velocity shift less than 0.68 km s^{-1} implies that the magnetic field strength is $\lesssim 6$ mG (using a Zeeman coefficient of 0.114 km s^{-1}mG^{-1}). This upper limit is in good agreement with the field strengths found for Galactic OH (1720 MHz) masers: 1 - 16 mG (see Caswell 2004). Unfortunately, it is not possible to observe with higher spectral resolution while recording full polarization data on the ATCA.

The location of the OH (1720 MHz) masers is indicated on a composite image of the ATCA 6 cm continuum with *Chandra* X-ray contours superposed (from Lazendic, Dickel, & Jones 2003) in Figure 3. The relationship of the masers to other sources in 30 Doradus is discussed in detail in §4.1.

3.2. OH (1720 MHz) Masers in N49

Two OH (1720 MHz) maser spots are detected just west of the center of N49, both with a center velocity of 278.2 km s^{-1}. The stronger of the two masers has a peak flux density of $\sim$ 35 mJy beam^{-1} (6σ). An image of the N49 1720 MHz continuum with OH (1720 MHz) maser emission contours superposed is shown in Figure 4, and a Stokes I profile toward the peak maser emission is shown in Figure 5. In order to verify our detection we split the N49 data into two approximately equal halves, each containing $\sim$ 7.5 hours of data and spanning $\sim$ 12 hours of $U-V$ coverage, and imaged them separately. The brighter maser spot is weakly detected in the two independent images. Comparisons of the maser data with previous observations of N49 are presented in §4.2.

The SNR N49B (0525-660) is also located within the primary beam of our ATCA data. No masers were detected toward this source.

4. DISCUSSION

4.1. Nature of the 30 Doradus OH (1720 MHz) Masers

The OH (1720 MHz) masers detected toward 30 Doradus are likely of the star-formation variety. The masers are located $\sim 2''$ NW of an optical and radio peak called "Knot 1" by Walborn & Blades (1987, see Fig. 3). Recent high resolution HST optical and ground based near infrared observations of this region show numerous massive young stars in the vicinity of "knot 1", many of them still deeply embedded (Rubio et al. 1998). Furthermore, the 30 Doradus OH (1720 MHz) masers appear to lie on the southern edge of a clump of molecular H_2 gas observed by Rubio et al. (1998). The masers are also coincident with the intersection of two large molecular clumps (in projection) traced by CO(1–0) observed by Johansson et al. (1998) using the SEST telescope. One, lying just NE of the maser location is has $v_{lsr} \sim 249$ km s^{-1} and $\Delta v \sim 10$ km s^{-1} (cloud 30Dor-10) while the other lies just to the SW and has $v_{lsr} \sim 246.5$ km s^{-1} and $\Delta v \sim 3$ km s^{-1} (cloud 30Dor-12). These velocities are in fair agreement with those of the OH (1720 MHz) masers (243.0 km s^{-1}).

A recent search of the 30 Dorodus region for SNRs by Lazendic, Dickel, & Jones (2003) using radio, optical, and X-ray data did not yield any detections near the maser locations. However, the masers are located fairly close (in projection) $\sim 26''$ or 6.5 pc to a Wolf-Rayet cluster of stars called R140 (see Portegies Zwart, Pooley, & Lewin 2002, also see Fig. 3). Recent *Chandra* observations by Portegies Zwart, Pooley, & Lewin (2002) have revealed that this cluster is very bright in X-rays, and it is possible that the X-rays in combination with a shock driven by the Wolf-Rayet winds could effect the same type of conditions present in a SNR shock (Wardle 1999). It is unclear how far away the WR cluster could exert such an influence. Indeed, from Figure 3 it is clear that the X-rays fill a bubble devoid of radio continuum emission (Hα emission looks much the same) to the NW of R140. However, the edge of the bubble traced by X-rays does not appear to reach as far east as the maser location.

Two further arguments against an SNR interpretation for the strongest 30 Doradus OH (1720 MHz) maser are its high luminosity 1150 Jy kpc^2 (assuming a 50 kpc distance to the LMC) and strong right circular polarization (compared to left). The strongest Galactic SNR type OH (1720 MHz) masers (those in W28 and SgrA) have luminosities of ~ 500 Jy kpc^2 (Claussen et al. 1997; Yusef-Zadeh et al. 1999). Conversely, while not common, a few Galactic SFR OH (1720 MHz) masers have luminosities in excess of 3,000 Jy kpc^2 (in W49A and W51 for example, Gaume & Mutel 1987). With only one exception, SNR OH (1720 MHz) masers typically show equal amounts of right and left circularly polarized emission (see for example Brogan et al. 2000). Even the exception, SNR IC443 only has an excess

right circular polarization of 10% (Hoffman et al. 2003). In contrast the 30 Doradus OH (1720 MHz) maser has more than 2.5 times the flux density in RCP as LCP (see Fig. 2). Preferentially stronger masing in one circular polarization compared to the other is thought to originate from velocity gradients, and is common in SFR type OH masers (see for example Caswell 2004; Gaume & Mutel 1987).

It is surprising, however, that no mainline OH maser emission down to a 5σ rms noise level of $\sim$ 50 mJy beam^{-1} ($\sim$ 9 times weaker than the 1720 MHz RCP peak flux density, Fig. 2) has been detected (see §2; Brooks & Whiteoak 1997). It is uncommon to find Galactic SFR OH (1720 MHz) masers that are not also accompanied by mainline OH masers at 1665 and 1667 MHz. Indeed, the mainline masers are often stronger than those at 1720 MHz. For example, of the 34 SFR OH (1720 MHz) masers detected by Caswell (2004) and Szymczak & Gérard (2004) with accompanying mainline OH maser emission, less than 10% are significantly (more than three times) stronger than the coincident mainline masers. However, (Caswell 2004), has also serendipitously detected six isolated SFR (1720 MHz) masers (also see Lazendic et al. in prep. for CTB 33 and Koraleskey et al. 1998, for W3). That is, the masers were detected within the primary beam of the observations, but well separated from the mainline target locations. To date, no truly blind Galactic surveys for OH (1720 MHz) masers have been carried out so it is unclear to what extent isolated SFR OH (1720 MHz) masers exist even in our own Galaxy. However, due to the large primary beam of the ATCA at 18 cm ($\sim 30'$), the Caswell 1720 MHz survey of 200 southern mainline maser locations, covers an area of 50-deg^2. Thus it is clear that such masers are rare.

Despite a number of recent surveys, no H_2O, or CH_3OH masers have been reported in the literature near this location either (Beasley et al. 1996; Lazendic et al. 2002). The only other known maser in the 30 Doradus region is an H_2O maser that is located $\sim 35''$ NE of the OH (1720 MHz) maser. Its position from Lazendic et al. (2002) is also plotted on Figure 3 for reference.

To summarize, most of the evidence: coincidence with a region of high mass star formation, high maser luminosity, and preferentially right circularly polarized emission suggests a SFR origin for the 30 Doradus OH (1720 MHz) maser. The absence of mainline OH masers at this location is surprising but not exceptional. Unfortunately, Caswell (2004) also finds that unlike typical SFR OH (1720 MHz) masers, the few known isolated SFR OH (1720 MHz) masers also lack methanol and excited state OH masers. Thus further observation is unlikely to clarify this issue.

4.2. Nature of the N49 OH (1720 MHz) Masers

Accounting for distance, the N49 OH (1720 MHz) maser flux density ~ 35 mJy beam^{-1} is within the range observed for Galactic SNR OH (1720 MHz) masers (Claussen et al. 1997; Brogan et al. 2000). As described in §1, the presence of an isolated OH (1720 MHz) maser toward the SNR N49 is indicative of an interaction between the remnant and a molecular cloud. Several recent observations have confirmed the presence of molecular gas in the vicinity of N49. Mizuno et al. (2001) have observed this region in CO(1–0) with $2\rlap{.}'6$ resolution using the NANTEN telescope. N49 lies within the northwestern edge of their CO cloud M5263-6606 ($05^{\rm h}26^{\rm m}19.9^{\rm s}$, $-66°03'33''$ J2000), which has a center velocity of 285.5 km s^{-1} and $\Delta v = 6.8$ km s^{-1} (also see CO cloud no. 23 in Cohen et al. 1988). Recall that the maser position is $05^{\rm h}25^{\rm m}56.5^{\rm s}$, $-66°05'01\rlap{.}''5$ (J2000) and the center velocity is 278.2 km s^{-1} (Fig. 5). Banas et al. (1997) observed CO (2-1) emission toward the eastern and SE regions of N49 (coincident with the continuum peak) in the velocity range 281 to 291 km s^{-1} using the SEST telescope and $23''$ resolution. The CO velocity peak, 286 km s^{-1} is somewhat higher than that of the OH maser at 278.2 km s^{-1}, but is still in reasonable agreement. Especially when one considers that Banas et al. used the velocity range 263-280 km s^{-1} for baseline subtraction, possibly affecting the apparent extent of the CO line. Curiously however, the CO(2–1) emission only barely extends far enough west to encompass the maser emission. Indeed the CO emission is strongest at the bright SE boundary of the SNR (Banas et al. 1997). Unfortunately, Banas et al. did not observe exactly at, or west of the maser locations. It would be interesting to obtain higher sensitivity, higher J CO observations at the location of the maser emission to look for evidence of shocked thermal molecular gas.

Further evidence for an interaction comes from the presence of faint diffuse infrared emission from the SE part of the remnant. Figure 6 shows a $J-$band (1.25 μm) 2MASS image superposed with the 1720 MHz continuum and maser contours. The diffuse $J-$band near-IR emission originates from warm dust, and possibly hydrogen recombination lines presumably heated and ionized by the passage of the shock (see for example Rho et al. 2001, for SNR IC443). From the near-IR morphology, together with that of the CO emission, we might reasonably expect that any maser emission would be in the southeastern region. However, Lockett, Gauthier, & Elitzur (1999) find that the OH (1720 MHz) maser collisional pump becomes less efficient for higher dust optical depths and temperatures ($T_d \gtrsim 100$ K). In this case, it is then, not surprising to see a lack of masers toward the regions of near-IR dust emission. Additionally, N49 has the highest optical surface brightness of any SNR in the LMC (Vancura et al. 1992). Like the radio continuum, the optical emission is strongest toward the southeastern regions of the SNR, although it is more extended than the near-IR emission shown in Fig. 6. From optical spectroscopy (Vancura et al. 1992) find that about 1/3 of the optical emission comes from shocks with speeds $\gtrsim 200$ km s^{-1}, while another

1/2 comes from shocks with speeds of $\sim$ 100 km s^{-1}. Such high shock speeds are also not conducive to SNR OH (1720 MHz) maser emission, since the collisional pump requires slower C-type (non-dissociating) shocks in order to form a sufficient column of OH.

Interaction with the molecular cloud is also evident from the properties of the X-ray emission from N49. Figures 7a,b show the hard and soft X-ray emission from N49 observed by *Chandra* (Park et al. 2003). Park et al. (2003) suggest that the soft and hard X-ray emission observed toward the eastern part of the SNR originates from a decelerated shock transmitted through the cloud, and from a shock reflected off the cloud back into the SNR interior, respectively. In Figure 7a,b, the X-ray emission from SGR 0526-66 is apparent (especially in hard X-rays) towards the NE, in addition to more extended emission from the SNR, concentrated to the SE. The SGR is thought to be the neutron stellar remnant of the N49 progenitor star. There is no obvious correlation of X-ray emission with the maser locations, although there is some indication of an enhancement in the hard X-rays (Fig. 7a). Most interestingly, there is little evidence that the soft X-rays are absorbed toward the SE part of the remnant where the CO, IR, and radio continuum emission peak. This may be an indication that the bulk of the CO cloud lies behind the SNR.

In many respects, N49 closely resembles the Galactic OH (1720 MHz) maser SNR 3C391. For this SNR, the brightest CO (2-1) emission is also coincident with the brightest radio continuum emission, but one of the 3C391 masers lies well away from the radio continuum and CO emission peaks (Frail et al. 1996; Reach & Rho 1999). In the case of 3C391, it is clear that the bulk of the CO cloud lies in front of the SNR, because the soft X-rays are heavily absorbed toward the peak CO and radio continuum regions (Chen & Slane 2001). This displacement of the maser emission from what seem to be the most obvious locations, i.e. places where there is a very clear indication of an interaction, is likely due to a combination of the physical conditions and the need for velocity coherence along the line of sight. Thus although an SNR may be interacting with a molecular cloud over a large surface area, only in those places where the temperature and density fall within the range needed for the collisional pump can masers form. Additionally, since masers are beamed, we can only observe masers where the shock front happens to be moving perpendicular to our line of sight, hence providing the requisite velocity coherence and beaming in our direction.

4.3. Detection Statistics

Although it is known that Galactic SFR OH (1720 MHz) masers are relatively rare, as mentioned previously, no truly blind survey of star forming regions has been carried out. When sources are selected based on previous detections of either mainline OH or methanol

masers, OH (1720 MHz) masers are detected 10-20% of the time (Szymczak & Gérard 2004; Caswell 2004). However, the recent serendipitous detection of six isolated SFR OH (1720 MHz) masers by Caswell (2004), suggests that such masers could be more numerous than previously suspected. In any case, based on the currently known data, it is not surprising that we only detect one SFR variety OH (1720 MHz) maser in 30 Doradus. What is actually more surprising is the lack of mainline OH, H_2O and CH_3OH masers in the LMC (see Scalise & Braz 1982; Beasley et al. 1996).

Of the 19 Galactic SNRs with positive OH (1720 MHz) maser detections ($\sim$ 10% of known Galactic SNRs), six (30%) would have at *least* one maser with a flux density $\gtrsim$ 30 mJy at the distance of the LMC (Frail et al. 1996; Green et al. 1997; Claussen et al. 1997; Koraleskey et al. 1998). A number of OH (1720 MHz) masers have also been observed toward the circumnuclear disk (CND) around the Galactic center which have properties similar to those found in SNRs, and would also be detectable at the distance of the LMC (Yusef-Zadeh et al. 1999). Based on these statistics it is not surprising that we detect SNR OH (1720 MHz) maser emission from one of the seven SNRs surveyed. (including the two 30 Doradus SNR candidates from Lazendic, Dickel, & Jones 2003).

5. SUMMARY AND CONCLUSIONS

In an ATCA search for OH (1720 MHz) masers toward 30 Doradus and four LMC supernova remnants, we have discovered two new maser regions. To our knowledge these are the first detections of OH (1720 MHz) masers in the LMC. One region of maser emission is coincident with the young star cluster in 30 Doradus known as "Knot 1", and is almost certainly of the star formation variety. Our spectral resolution (0.68 km s^{-1}) is insufficient to detect the Zeeman effect from the strongest of the 30 Doradus OH (1720 MHz) OH masers, leading to an upper limit to the field strength of 6 mG, in good agreement with the fields found in similar Galactic masers. The 30 Doradus OH (1720 MHz) masers are somewhat unusual for SFR masers, since no mainline masers are detected in their vicinity. However, a few isolated SFR OH (1720 MHz) masers have also recently been detected in our Galaxy (Caswell 2004). The other region of OH (1720 MHz) maser emission was detected toward the LMC SNR N49. The masers are located just west of a CO molecular cloud detected by Banas et al. (1997), and are indicative of an interaction between the SNR and the molecular cloud. Although the statistics are low, the detection rate seems consistent with that seen for Galactic SFR and SNR type OH (1720 MHz) masers – both of which are low.

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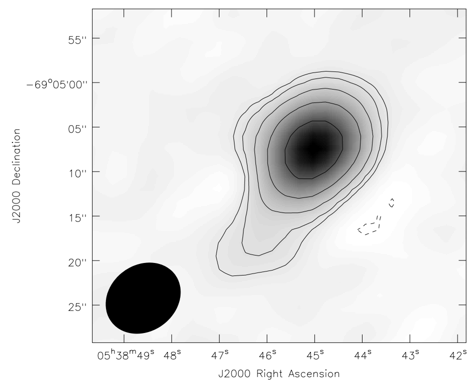

Fig. 1.— ATCA Stokes I image of the strongest 30 Doradus OH (1720 MHz) maser channel at $v_{lsr} = 243.0$ km s^{-1}. The contour levels are at $-15, 15, 25, 50, 100,$ and 200 mJy beam^{-1}. The peak flux density is 318 mJy beam^{-1}. The resolution of this image is $8.9'' \times 7.4''$ P.A.$= -54°$. The beam size is shown on the lower left corner of the image, and the rms noise in the image is 5 mJy beam^{-1}.

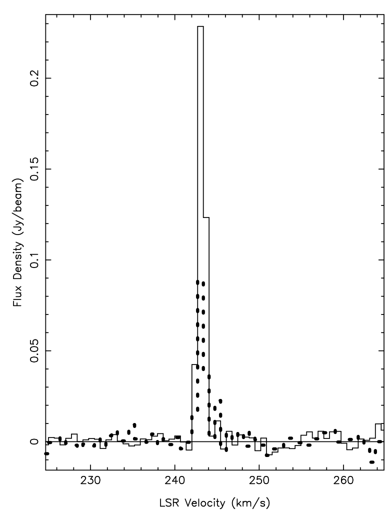

Fig. 2.— ATCA Stokes RCP (solid) and LCP (dotted) line profiles of the 30 Doradus maser at the peak position. The position of the peak is $05^{\rm h}38^{\rm m}45^{\rm s}$, $-69°05'07''$ (J2000).

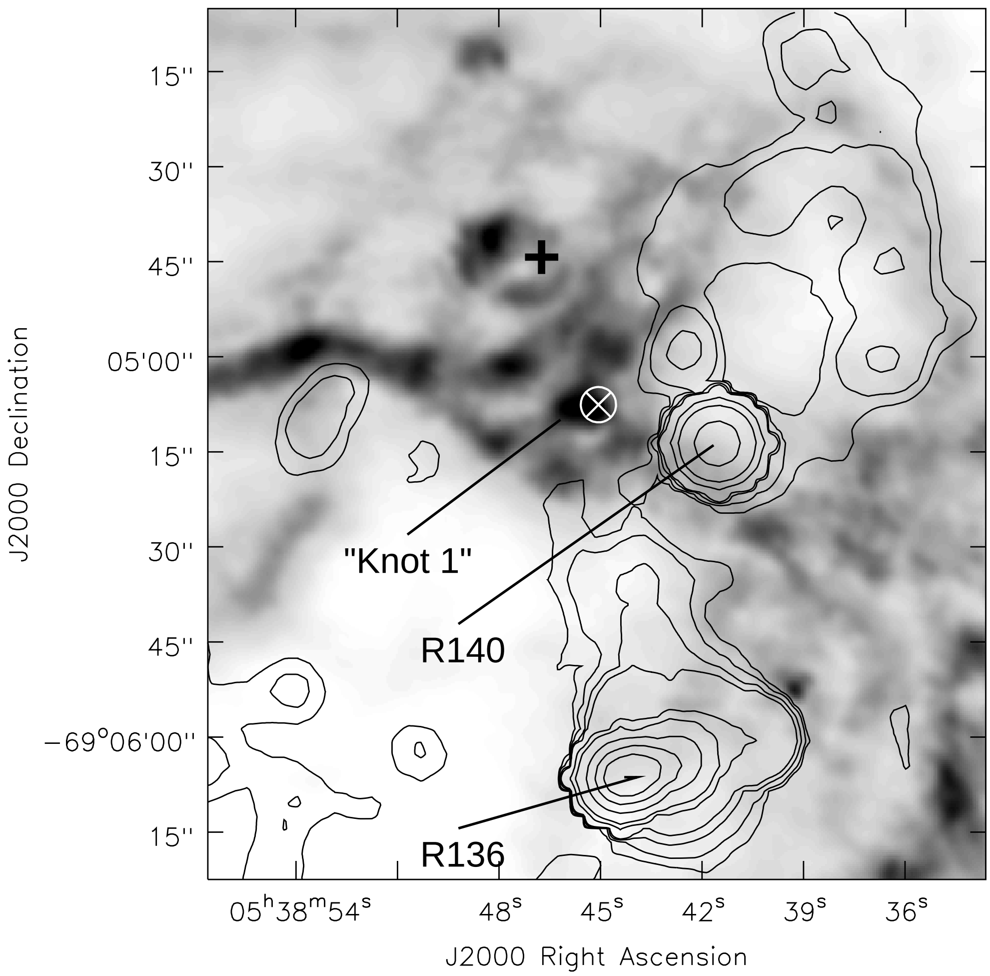

Fig. 3.— Composite image of 30 Doradus showing the ATCA 6cm continuum in greyscale and *Chandra* X-ray contours from Lazendic et al. (2003). The resolution of the 6 cm continuum and X-ray images are $1\farcs8 \times 1\farcs7$ and $2''$, respectively. The location of the OH (1720 MHz) masers is indicated by the white $\otimes$ symbol. The position of the only other known maser in the 30 Doradus region: an H_2O maser from Lazendic et al. (2002) is indicated by the black + symbol. The locations of the young star forming cluster "Knot 1" and the two Wolf-Rayet X-ray star clusters R140 and R136 are also indicated for reference.

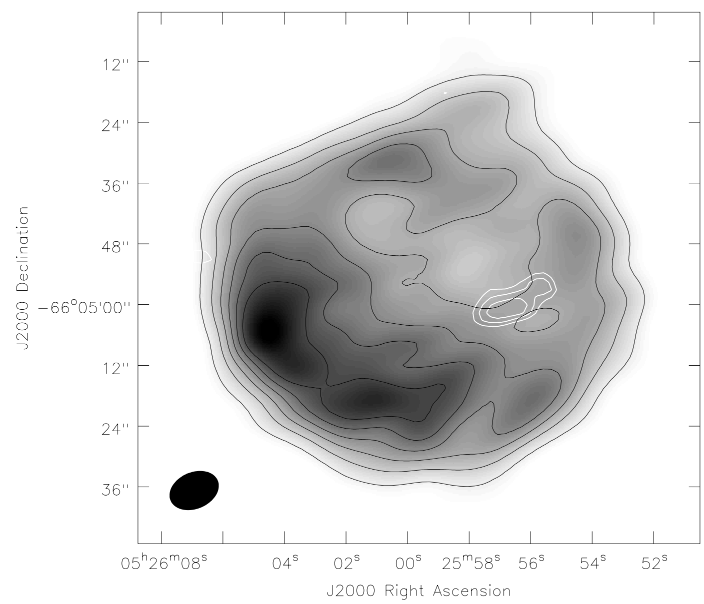

Fig. 4.— Composite image of the N49 1720 MHz continuum (greyscale and black contours) superposed with white Stokes I OH (1720 MHz) maser emission contours from the peak channel at $v_{lsr} = 278.2$ km s^{-1}. The resolution of the images is $10.1'' \times 7.2''$ P.A. $-67°$ (beam is indicated in lower left of the image). The continuum contours levels are 5, 10, 20, 30, 40 mJy beam^{-1} and the continuum peak flux density is 47 mJy beam^{-1}. The maser contours levels are 20, 25, 30 mJy beam^{-1} and the peak maser flux density is 35 mJy beam^{-1}. The continuum rms noise is 0.6 mJy beam^{-1}, while the rms noise in the spectral line is 5.8 mJy beam^{-1}.

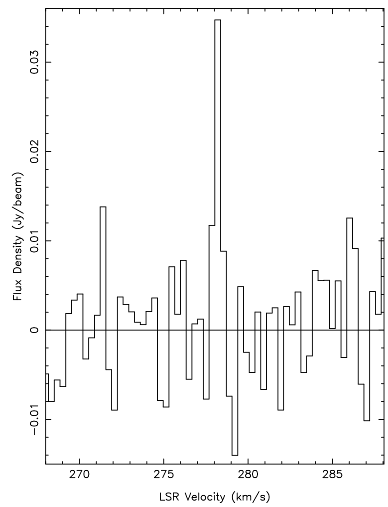

Fig. 5.— ATCA Stokes I line profile of the N49 OH (1720 MHz) maser at the peak position. The position of the peak is $05^{\mathrm{h}}25^{\mathrm{m}}56.5^{\mathrm{s}}$, $-66°05'01.5''$ (J2000).

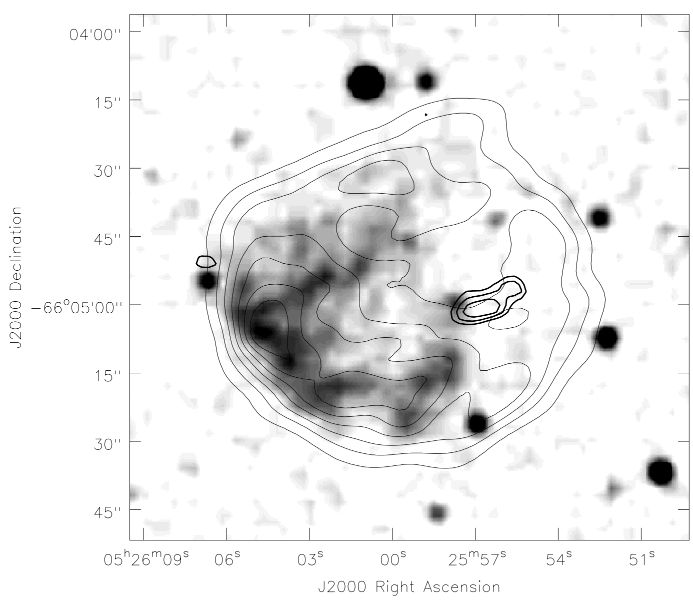

Fig. 6.— 2MASS 1.25 μm $J-$band image with the 1720 MHz continuum and maser emission contours from Figure 4 superposed.

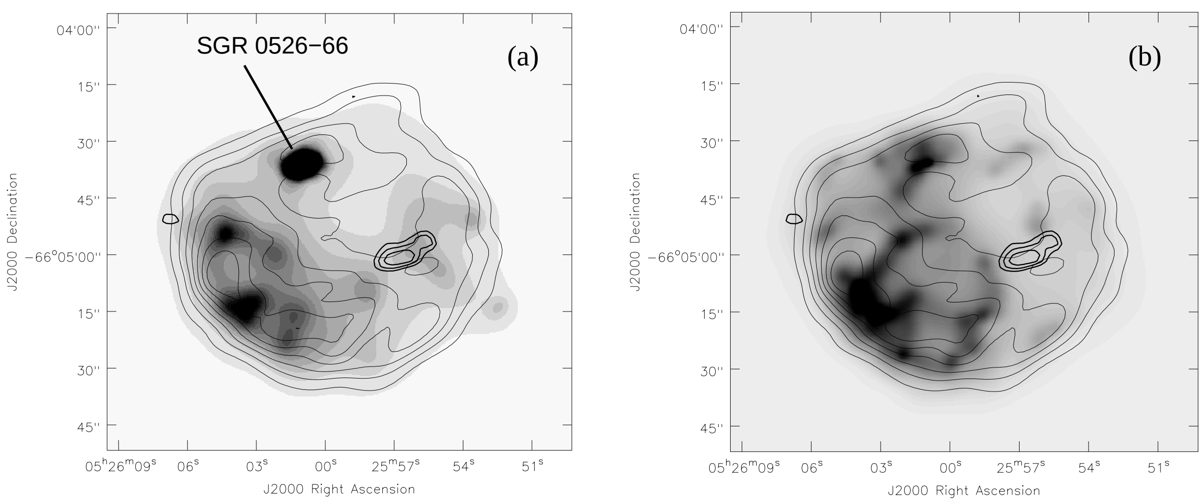

Fig. 7.— ATCA 1720 MHz continuum (black) and OH (1720 MHz) maser (white) emission contours from Figure 4 superposed on (a) *Chandra* hard (1.6-8.0 keV) X-ray greyscale and (b) *Chandra* soft (0.3-0.75 keV) X-ray greyscale from Park et al. (2003). The X-ray images have been adaptively smoothed.

Table 1. Observational Parameters of ATCA OH (1720 MHz) maser Observations

Name	Position[a] (J2000)	Integration[b] (hours)	beam ($'' \times ''$ (P.A.$^\circ$))	Channel Width[c] (km s^{-1})	Line RMS (mJy beam^{-}
30 Doradus	$05^{\rm h}38^{\rm m}45^{\rm s}$, $-69^\circ05'07''$	21.9	8.9×7.4 (-54)	0.68	4.3
N49	$05^{\rm h}26^{\rm m}00^{\rm s}$, $-66^\circ05'00''$	15.7	10.1×7.2 (-67)	0.34	5.8
N44	$05^{\rm h}23^{\rm m}18^{\rm s}$, $-67^\circ56'00''$	8.1	10.7×6.8 (-25)	0.34	8.5
N120	$05^{\rm h}18^{\rm m}42^{\rm s}$, $-69^\circ39'30''$	9.0	10.7×6.4 (-30)	0.34	7.1
N132D	$05^{\rm h}25^{\rm m}02^{\rm s}$, $-69^\circ38'36''$	7.8	9.8×6.8 (-20)	0.34	8.3

[a]Positions from Williams et al. (1999) except for 30 Doradus which is the position of the observed O (1720 MHz) maser.

[b]Approximate time on source.

[c]The spectral resolution is 1.2× channel width.